

# To Drink Without Risk: The Use of Ultraviolet Light to Disinfect Drinking Water in Developing Countries

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February 1, 1995

## **Introduction**

Waterborne diseases such as cholera, typhoid fever, gastroenteritis, dysentery, and infectious hepatitis kill more than 400 developing-world children every hour, and result in the loss of billions of hours of worker productivity each year. Home-delivered, municipal, tap water is uncommon in developing countries, and two out of three people in the world must fetch water from outside their homes. In India, water purity issues are particularly important during the monsoon season when heavy rainfall washes raw sewage and other contaminated material from the fields into the wells and surface water.

To address this significant public health problem, there is an effort underway at the Lawrence Berkeley Laboratory (LBL) to introduce a water disinfection system using ultraviolet light to rural villages in India. The goal of this project is to design and field-test a water disinfection device for developing countries that is durable, easy to use, inexpensive, and can be constructed and maintained locally.

The UV disinfection project team began its research early in the summer of 1993. Efforts were increased considerably in August 1993, when an outbreak of cholera was reported in India, Thailand, and Bangladesh (Altman, 1993). A year later, the cholera epidemic continues to be a problem in India — in the state of Bihar, between the months of May and August 1994, approximately 2200 people died from cholera (Times of India, 1994). Other waterborne diseases also pose a serious health threat to Indian communities. In the state of Orissa alone, there are approximately 300 infant deaths per day as a result of waterborne gastrointestinal diseases (Alkari, 1994).

The UV disinfection research effort has received funding support from the United States Agency of International Development, the United States Department of Energy, the Rockefeller Foundation, the Joyce Mertz-Gilmore Foundation, and the Pew Foundation's award to project-team member, Dr. Ashok Gadgil. General Electric (US), and Philips (the Netherlands) donated UV lamps to the project for field tests. The researchers are establishing the program in India and hope to expand to other countries that need help combating waterborne pathogens such as Bangladesh and Thailand. In addition, the project has recently received an expression of USAID interest in supporting test sites in Mexico. As in Asia, cholera is a problem in Latin America, particularly in Peru.

The researchers estimate that the UV disinfection system can provide clean drinking water for approximately 5¢ per villager annually. The disinfection process is highly energy-efficient and uses approximately 40,000 times less primary energy than the standard alternative — boiling water over a cookstove. The provision of a simple and inexpensive method for disinfecting drinking water will save

the lives of many people, particularly the lives of children, who are the most susceptible to diarrheal diseases. Because women are primarily responsible for providing their families with water as well as bearing and caring for children, the UV disinfection system has the potential to greatly improve women's quality of life by reducing their workloads as well as the number of children they lose to waterborne diseases.

The disinfection system has proved successful in the laboratory. Although the equipment is also expected to perform well in the field, the primary challenge to introducing this technology to rural communities will be integrating the technological system into the community structure. The community management of the disinfection system should ensure access for all villagers and provide built-in incentives for maintenance and repair.

### **The Ultraviolet Water Disinfection System**

The proposed technology uses ultraviolet (UV) light to eliminate waterborne pathogens (germs, viruses, and molds) from the local water supply. Ultraviolet light is classified into three different wavelength ranges: UV-C from 100 nanometers (nm) to 280 nm; UV-B from 280 nm to 315 nm; and UV-A from 315 nm to 400 nm. UV-C light is "germicidal"; that is, it destroys germs, viruses, and other pathogens by inactivating their DNA and thus their ability to reproduce. Light with a wavelength of 254 nm gives the highest germicidal efficacy in the ultraviolet range. Because this is the wavelength at which a low-pressure mercury vapor lamp emits roughly 90% of its light, the standard fluorescent lamp technology can be used in the disinfection system.

The glass tubes of the fluorescent lamps that light our offices, and sometimes homes, are coated with a phosphor that absorbs ultraviolet light and gives off visible light. The lamp that is used in the UV disinfection system is similar to a standard fluorescent lamp, but the lamp tube is not coated with phosphor and is made of a special glass that is transparent to UV light. This "germicidal" variety of lamp is already manufactured by many large companies that make standard fluorescent lamps. Consequently, lamps, ballasts, and starters for the UV disinfection system can be bought "off the shelf," with the full benefits of mature volume production (i.e., at low cost and free of technical bugs).

Before contaminated water enters the UV disinfection chamber, the water must be filtered to reduce turbidity.<sup>1</sup> If water is pumped into the chamber directly from a ground water source (e.g., a shallow tube well), filtering is often unnecessary because the turbidity of ground water is low. The turbidity in surface water can be reduced by using an appropriate sand filter.

In the disinfection chamber, water is disinfected by exposure to UV light. In the present design, the UV chamber is constructed from sheet metal and contains a UV lamp under a reflector. A shallow stream of water flows under the UV lamp through channels in a metal tray.

Graphics Credit: Global Efficiency Monitor, 1994.

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<sup>1</sup> "Turbidity" refers to the cloudiness of the water, usually a result of suspended particulates. The water needs to be clear in order for the UV light to travel all the way through it during the disinfection process.

The figure shows a 36-inch (91 cm) long, 1-inch (2.5 cm) diameter, 36-watt UV lamp located under a curved aluminum reflector. The water depth is 12.5 cm (about 4 inches). At the rated flow of 30 liters per minute through the UV device, the energy density of the UV light shining on the water is 20 milliwatt-sec/cm<sup>2</sup> — more than enough to kill 99% of the waterborne pathogens (Wolfe, 1990). The chamber has an electrical interlock so that the lamp cannot operate unless the lid to the chamber is shut tightly. The interlock system eliminates the risk to system operators of exposure to the harmful UV light. From the disinfection chamber, the water is delivered through a spigot to the user or can be channeled into a small storage tank for potable water. Gravity is used to move water through the system. Consuming a total of 40 watts, the system disinfects approximately 30 liters of water per minute. This is more than three times the flow from a typical U.S. bathtub faucet or a common garden hose.

### **The Cost of Ultraviolet Disinfection**

The project team believes that the introduction of ultraviolet water disinfection systems to Indian villages can, at a very low cost, greatly reduce health problems associated with contaminated drinking water. The technology is potentially available to a large portion of the Indian population because so much of rural India has access to electricity. Approximately 70% of the Indian population is rural and about 80% of villages are connected to the electrical grid. Although the majority of houses in electrified villages are not directly connected, there is a central point in all electrified villages from which a community-owned water disinfection system could be powered.<sup>2</sup>

The estimated one-time capital cost of an ultraviolet system is \$500, including valve, fittings, and labor. The life of the stainless-steel chamber is expected to be approximately 40 years; the UV lamp requires replacement annually. At 12% discount rate, the annualized capital cost of the UV system is approximately \$60 per year. Assuming that the system is operational for 12 hours per day, and that the price of electricity is 8¢/kWh, the annual operating cost of a UV system is approximately \$44 (including the replacement UV lamp and the cost of electricity). Thus, the total annual cost is approximately \$104. It is assumed that the villagers provide their own storage tanks and sand filter; the raw materials for these components are readily available and inexpensive. These are not included in the present cost calculations.

Operating for 12 hours per day, the system will disinfect 7884 tonnes (7.9 million liters) of water annually. The cost of disinfecting water is thus about 1¢ per ton. Based on a per capita drinking water requirement of 10 liters per day, a single system can provide enough water for approximately 2200 villagers. Accordingly, a UV system could ensure potable water year-round for a community of 2200 people at a cost of about 5¢ per villager per year.

### **Ultraviolet Disinfection Compared to Other Water Treatment Techniques**

As noted by Wolfe (1990), the disinfection of drinking water with ultraviolet light first took place in the early 1900s. However, the systems were not highly successful for a number of reasons, including "high operating costs, poor equipment reliability, maintenance problems, and the advent of chlorination, which was found to be more efficient and reliable." The UV technology has improved and become less expensive since the turn of the century and has recently been gaining popularity, particularly in Europe. Currently, approximately 2000 water treatment plants in Europe use UV disinfection systems (Wolfe, 1990).

Despite its growing popularity in Europe, UV disinfection is not a common water treatment method in developing countries. Some people in developing countries obtain safe drinking water from deep tubewells. Others disinfect their water with chlorine or by boiling it over a cookstove. We do not claim that ultraviolet disinfection is the best choice for water disinfection under all circumstances, but believe that it is a viable and preferable alternative in certain situations. Below, ultraviolet disinfection is compared to other common treatment strategies.

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<sup>2</sup> One model of the present UV system is powered by a 12-volt car battery that is recharged when electricity from the grid is available. This simple modification allows system operation in villages where the power supply is intermittent. For a higher cost, the system can also operate off photovoltaic panels.

### *Deep Tubewells*

In India, many rural families obtain drinking water from deep tubewells. Because the wells are more than 200 feet deep, the water has been sealed beneath an impermeable layer of earth for a long time and is commonly bacteria-free. One disadvantage of obtaining water from a deep tubewell is that many people dislike the taste. Because the water is old, it has a high dissolved salt content, and many people prefer the taste of fresher, surface water. Additionally, deep tubewells can be expensive and time-consuming to construct because of the specialized deep-drilling equipment that is required.

Compared to deep tubewells, UV disinfection has several advantages. The UV disinfection process can be used to disinfect fresh water and has no effect on the smell or flavor of the water. Moreover, the system is less expensive and less time-consuming to construct. An additional benefit of the UV system is that, unlike a tubewell, it can be easily moved from one place to another as needed.

### *Chlorine Disinfection*

The water supplies in many rural communities are disinfected with chlorine bleach. Chlorine disinfection kills all pathogens, including giardia. In addition, chlorine has a residual effect; that is, if bacteria are reintroduced into a chlorinated water supply, the new bacteria will die. Although chlorine disinfection is a well-proven technique, it has a few disadvantages. Often, people dislike the taste and smell of chlorinated water. In addition, because it is easy to overdose water with chlorine, it is necessary for a trained person to test chlorine levels before water is consumed. Most importantly, it is necessary to maintain a steady supply of chlorine bleach; the current cholera outbreaks in India are largely attributed to a breakdown in its supply chain (Times of India, 1994).

Unlike chlorine disinfection, UV disinfection does not kill giardia or have a residual effect on bacteria that may be reintroduced into the water after UV treatment. However, in areas where giardia is not a problem and where long-term storage of drinking water is unnecessary, UV disinfection can provide a useful treatment alternative. UV disinfection is comparable in cost to chlorine disinfection and has several distinct advantages. As mentioned above, UV disinfection has no effect on the smell or flavor of the water. In addition, there is no risk of overdose as there is with chlorine. The most significant advantage of the UV system over chlorine disinfection is that the system is not vulnerable to a breakdown in the supply chain. Once the initial components are provided, and so long as the UV lamp is replaced annually, the system can operate for years.

### *Boiling Water Over a Cookstove*

Although very few Indian villagers disinfect their drinking water by boiling it over a cookstove, this is common practice among rural families in some developing countries (e.g., China). The burning of biomass fuels for water disinfection increases the pressure on the forests. In many areas of India as well as other developing countries, deforestation is extensive, wood fuel supplies have dwindled, and families are forced to depend on “residue fuels” such as crop residues, cattle dung, and twigs. Because of their responsibility for meeting household energy needs through fuel collection and use, women often bear the largest burden of fuelwood scarcity. Collection of fuelwood is an increasingly difficult chore for rural women in India. In addition, there are serious health risks associated with smoke inhalation from biomass-fueled traditional cookstoves. Generally, the health risks for women and children are much greater than those for men because women, as the household cooks, often spend many hours each day at unvented, indoor hearths with their children nearby.

The advantages of UV disinfection over the treatment of water by boiling are significant. The UV system puts no pressure on forests and does not require someone to tend a smoky fire while waiting for water to boil. In addition, the energy savings associated with the UV system compared to burning biomass fuels are enormous: as mentioned above, the UV disinfection technique uses approximately 40,000 times less primary energy than boiling water over a cookstove.<sup>3</sup>

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<sup>3</sup> Based on a cookstove using solid fuel at 15 percent efficiency; 10 percent is typical efficiency for biomass fuels.

In summary, the UV disinfection system represents a useful addition to the choice of water treatment technologies for developing countries. The UV system has distinct advantages where deep tubewells are not feasible, drinking water is needed everyday, and waterborne pathogens are a problem. Additionally, as discussed below, the UV disinfection system can significantly improve the quality of life for rural women.

### **Improving the Lives of Rural Women**

Perhaps the greatest advantage of a simple and inexpensive water treatment technique such as the UV system is the extent to which it can improve the lives of rural women in developing countries. Improving the quality of drinking water can significantly reduce the morbidity and mortality in children and infants, and also the burden on their mothers of caring for sick children and the grief of losing them to diarrheal diseases.

That improving the survival rate and health of children will reduce population growth is not immediately obvious to many people. Yet the technical literature unanimously asserts that improving basic health, particularly reproductive and child health, decreases birth rates (Easterbrook, 1994). Many rural women in developing countries are caught in a perpetual cycle of pregnancy and loss of their children to disease. In regions of high infant mortality, women bear many children to ensure that at least a few children will survive to adulthood and care for their aged parents. Even when pregnant, most women continue to work long days<sup>4</sup>, and caring for sick children increases their work burden even further.

A leading cause of death for developing-world children is unsanitary drinking water. According to UNICEF, in 1993, 3.8 million developing-world children under age 5 died from diarrheal diseases caused primarily by impure drinking water (Easterbrook, 1994). Given a clean supply of drinking water, the risk of losing one's child to disease is reduced dramatically. For women, this means less time enduring the physical strain and health risks of pregnancy; less time caring for, and worrying about, sick children; more time for economic activities; and more time for themselves and their families.

### **Barriers and Challenges to the UV Disinfection System**

Although the UV technology itself is easy to construct, use, and maintain, integrating the use of a new technology into a community's daily routine can be challenging. The greatest benefits of the UV system will be achieved where all villagers have access to, and use, the disinfected water. Consequently, care must be taken to ensure that the poorer and less-educated members of the community also have access to treated water. In addition, there must be a community strategy for maintaining the system; the simplest solution may be for someone in the village (e.g., a school teacher) to earn additional income for overseeing the system.

While access must be ensured to all community members, special care should be taken to ensure that women are educated about the operation of the disinfection system. Because women are typically in charge of obtaining the family water supply, it is important for women to be knowledgeable about, and comfortable with, the technology. As mentioned above, the typical workday of a rural woman is long, and any technology that she perceives as increasing her work burden is likely to go unused — not from a lack of caring, but from a lack of time and physical stamina.

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<sup>4</sup> Studies of rural women in five Indian villages concluded that women worked more than 13 hours per day, on average. Time-use studies from Africa, Latin America, and other parts of Asia show similar results. (Cecelski, 1987)

### **Current Status of Development**

Two firms in India have taken up manufacture of UV devices of LBL design. These units are now being field-tested in India. The UV project team originally comprised Dr. Ashok Gadgil, Dr. Art Rosenfeld, and Mr. Derek Yegian. The present team includes Dr. Gadgil, Mr. Yegian, and Ms. Catherine Lukancic. The LBL project team is now working in the laboratory to significantly lower the system cost without compromising performance. In the current fiscal year (FY95), the researchers hope to receive feedback regarding the field performance of several test units at various rural locations in India.

### **Conclusion**

The UV disinfection system represents a useful water-treatment alternative for developing countries. The UV system is durable, easy to use, inexpensive, and can be constructed and maintained locally. Researchers at the Lawrence Berkeley Laboratory estimate that the system can provide drinking water to rural communities for approximately 5¢ per villager annually. The provision of a simple and inexpensive method for disinfecting drinking water will save the lives of many people — particularly the lives of children, who are the most susceptible to diarrheal diseases. In addition, the UV disinfection system can greatly improve the quality of life for rural women by reducing their workloads as well as the number of children they lose to waterborne diseases. Finally, because the UV system uses approximately 40,000 times less primary energy than the common developing-world practice of boiling water over a cookstove, UV disinfection has significant environmental advantages both locally and globally. On a local level, the substitution of UV disinfection for the burning of biomass fuels reduces indoor and outdoor air pollution as well as pressure on the forests; globally, such a substitution reduces emissions of carbon dioxide, a greenhouse gas associated with global climate change.

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